

# THE PETROLOGY OF ALKALINE DYKES FROM THE TUGTUTOQ AREA, SOUTH GREENLAND

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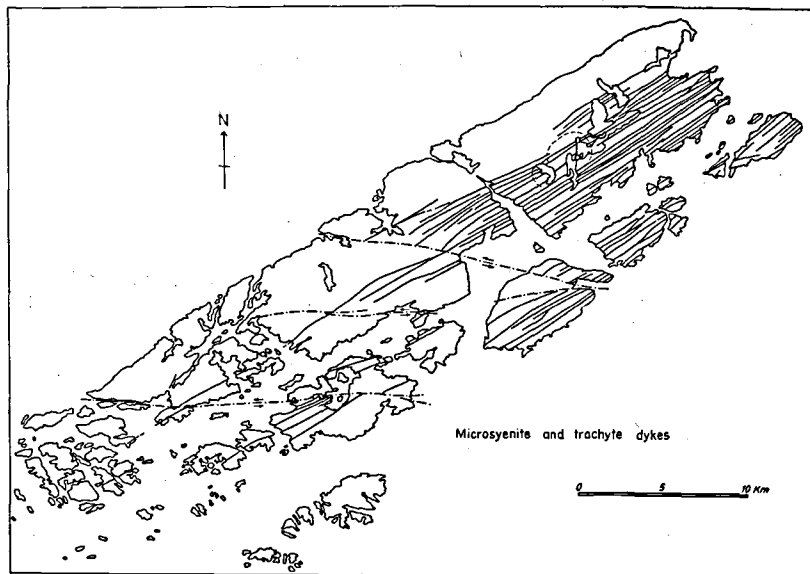
MACDONALD, R.: The petrology of alkaline dykes from the Tugtutôq area, South Greenland. *Bull. geol. Soc. Denmark*, vol. 19, pp. 257-282. Copenhagen, December 17th, 1969.

Intermediate to acid alkaline dykes of Gardar age from the Tugtutôq region, South Greenland, form an almost continuous series from trachydolerites through hastingsite- and riebeckite-bearing micro-syenites to riebeckite and aegirine microgranites. Chemically, the series shows a transition from anorthite- and nepheline-normative types to acmite- and quartz-normative varieties. Though the dykes are thought to have been ultimately derived by fractionation of basaltic magma, several processes have tended to alter the original liquid compositions, including loss of a vapour phase, devitrification of the acid dykes, alkali-ion exchange effects and alteration of amphibole. The evolutionary trends of the magmas cannot therefore be closely defined.

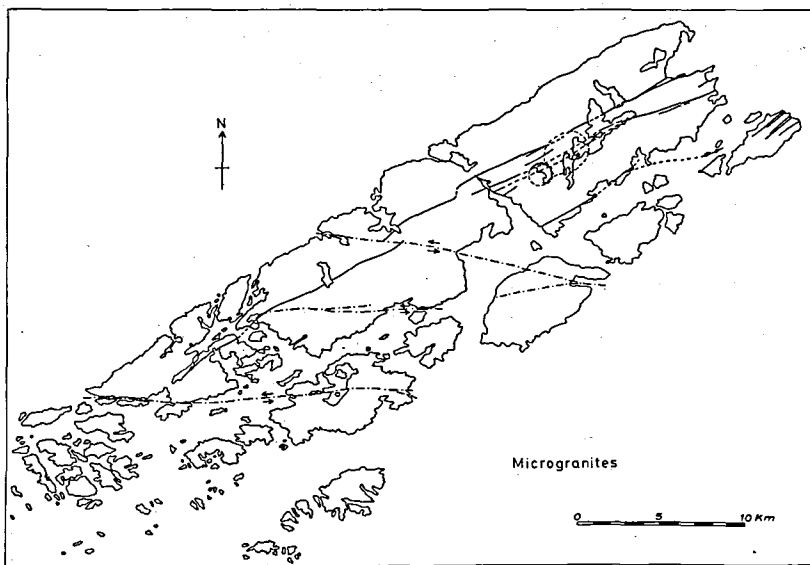
The rocks which form the basis of the study were collected on the islands of the Tugtutôq region, South Greenland (figs 1 a, b) where they occur as dykes, intruded during the *Gardar* period, the youngest division of the Precambrian in South Greenland. Reviews of the chronology and geological history of the Precambrian in this part of Greenland have been presented by Bridgwater (1965), Berthelsen and Noe-Nygaard (1965) and details of Gardar igneous activity in the Tugtutôq area were given by Upton (1962, 1964 a); the sequence of events is summarised in table 1.

Intrusion of the various Gardar igneous rocks was connected with large-scale faulting of the region. The dyke swarms which are of particular interest here, those trending NE-ESE, are parallel to pre-existing structures in the granitic basement and show no radial grouping around any plutonic centre. The complexes were formed at high crustal level and probably underlay alkaline central volcanoes, while the dykes, in view of their abundance, almost certainly acted as feeders to surface volcanism. Trachytic lava flows (rhomb-porphyrines) have been described by Stewart (1964) from the Ilímaussaq peninsula, occurring near the top of a thick sequence of mildly alkaline olivine basalts. These Gardar lavas, preserved in the eastern part of the province, represent relatively early Gardar volcanism. It is not yet clear whether the trachytic lavas were produced by fissure eruption or from one of the central volcanoes.

Gardar volcanism involved generation and uprise of olivine basalt magma much of which had a composition close to the critical plane of silica-undersaturation (Upton, in press). The dykes under discussion are the



a



b

Fig. 1. Distribution of (a) microsyenite and (b) microgranite dykes on Tugtutôq. From Upton (1964a).

Table 1. Sequence of Gardar igneous events in the Tugtutôq region

Late	Camptonitic dolerite dykes Small trachytes Intrusion of Central Complex ? Formation of diatremes
Mid	Large numbers of dykes on ENE trend Krydsø and Assorutit intrusions Doleritic/gabbro dykes, including 'giant-dykes'
Early	Hviddal composite dyke Thin ENE-WSW dolerites NW-SE olivine dolerites

more salic representatives of the intense dyke swarm encountered in granitic basement rocks on and around the eastern part of Tugtutôq. The abundant basic dykes of the region are not considered further, although it is assumed that the basaltic magmas that fed them were parental to the salic magmas, and that olivine-plagioclase fractionation plus subordinate clinopyroxene-ilmenomagnetite fractionation within the crust have played a major part in their evolution. Trachydoleritic dykes compositionally intermediate between the dolerite/gabbroic dykes and the microsyenitic (or trachytic) dykes also occur in considerable abundance. Generally these, and the dolerite/gabbro dykes, are found to precede the salic dykes.

One aim of this study was to examine closely evolutionary trends in the acid dykes, when alkali feldspar is thought to have been the dominant fractionating phase. Thirty new analyses of the dyke rocks and six new analyses of alkali feldspar phenocrysts have been made. In terms of composition the analysed dykes form an almost continuous series from the rocks of trachydoleritic affinities, through microsyenites (or trachytes) to riebeckite and aegirine microgranites. The normal index minerals of peralkalinity, such as riebeckite, are entirely absent from the more basic members of the suite, and chemically the series passes from silica-undersaturated to -oversaturated types and from anorthite-normative to acmite-normative varieties. Despite their continuity as a series, the dykes may have been intruded over a considerable time interval, very approximately around 1150 m. y. ago (Bridgwater, 1965) and certainly belong to a number of swarms. It is a basic assumption of this paper in grouping together members of different swarms, that each swarm has been derived from a similar source and shared a common evolutionary history.

Field data for the dykes may be found in Upton (1962, 1964 a). The dykes normally have chilled margins except in composite dykes where they have been intruded into a still-hot earlier component, and no evidence has been found for metamorphosed contacts, or for wall-rock contamination. In the composite dykes, with the exception of the remarkable feldspathic dykes or 'big feldspar dykes' (BFDs) (Bridgwater 1967, Bridgwater &

Harry, 1968), the younger central components are invariably more acidic than the initial intrusion.

No work on the BFDs of the Tugtutôq area has been done, in order to avoid overlap with Dr Bridgwater's study. These large, composite dykes are unusual in that they have earlier, alkali-rich (microsyenite) margins and later more basic (trachydoleritic or doleritic) centres. Though the centre may be chilled against the margins, normally there is complete gradation across the dykes. The chemical trends across the dykes are closely comparable to those in the other Gardar bodies, as shown on  $\Sigma$  Fe-Mg-alkalis diagrams (Bridgwater & Harry, 1968), and the BFDs seem to provide evidence of the existence of magma bodies differentiated prior to intrusion of the dykes.

## Petrography

The petrography of the dykes is summarised in table 2 and modes of analysed specimens listed in table 3 (pp. 275–276). Reaction series in the ferromagnesian minerals of the dykes are shown in fig. 2.

The trachydolerites used in this work, which are virtually aphyric, are not typical of the Gardar trachydolerites, which normally contain phenocrysts of sodic plagioclase, clinopyroxene and ore.

The trachydolerites and more basic microsyenites are typically holocrystalline except for the fine-grained marginal facies that are suspected of having originally been glass. With increasing richness in silica, however, increasing degrees of supercooling seem to have characterised the dykes, and the more acid dykes commonly show felsitic or spherulitic textures suggesting that they were predominantly glassy at first, acquiring their present textures by subsequent devitrification. The centres of the thicker acid dykes show microgranitic or granophyric textures.

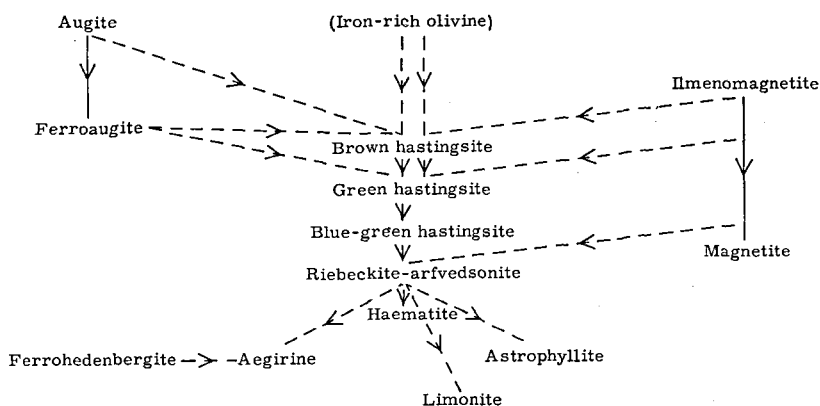


Fig. 2. Reaction series in the ferromagnesian minerals of the dykes.

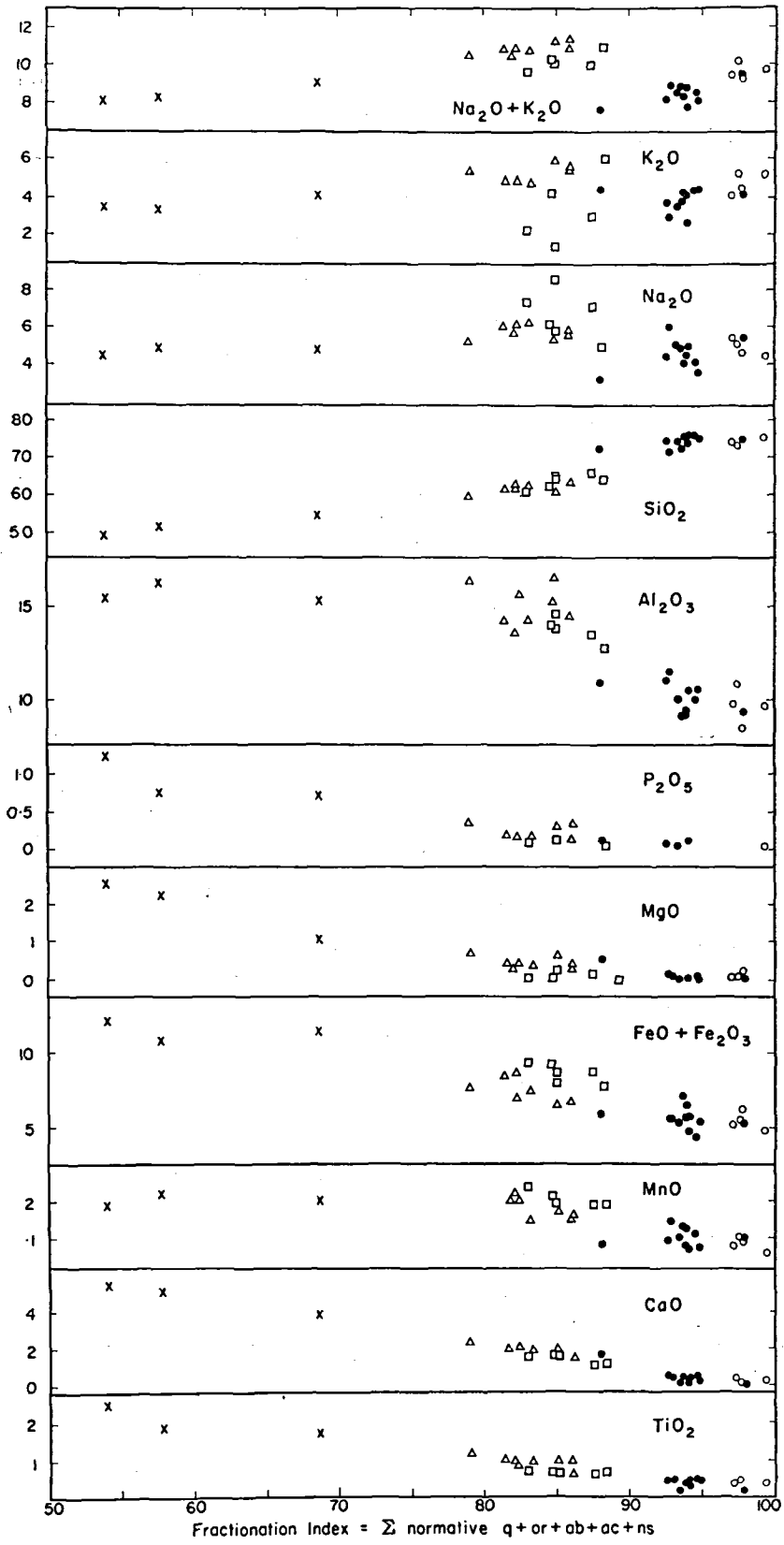
Table 2. Summary of petrography of Tugtutôq alkaline dykes

Rock Group	Phenocrysts	Groundmass
Trachydolerites	Scarce apatites	Cryptoperthitic feldspar (occasional oligoclase cores,) biotite, augitic pyroxene, ore, apatite. Textures – generally orthophyric.
Hastingsite microsyenites	Alkali feldspar (anorthoclase microperthite), fayalite pseudomorphs, pyroxene (augite-ferroaugite), ore, apatite, scarce hastingsite	Microantiperthitic feldspar, with occasional albite rims, hastingsite, riebeckite-arfvedsonite, limonite, ore, quartz, pyroxene, apatite, carbonate. Occasional vugs. Textures – trachytic.
Riebeckite microsyenites	Microperthitic feldspar Ore	Microantiperthitic feldspar, riebeckite-arfvedsonite, ore, limonite, quartz, zircon. Textures – trachytic, felsitic, spherulitic.
Riebeckite microgranites	Antiperthitic feldspar, quartz, ore, riebeckite-arfvedsonite (or aegirine aggregates pseudomorphing it).	Microantiperthitic feldspar, riebeckite-arfvedsonite, aegirine, ore, zircon, limonite, fluorite, astrophyllite. Textures – trachytic, spherulitic, felsitic, granophyric, microgranitic.
Aegirine microgranites	Antiperthitic feldspar, quartz, hedenbergite, fayalite pseudomorphs	Aegirine, microperthitic feldspar, quartz, riebeckite-arfvedsonite, astrophyllite. Textures – felsitic, trachytic, spherulitic.

## Petrochemistry

The distribution of the major elements in the dyke suite has been summarised in variation diagrams (fig. 3), using as abscissa the sum of the normative components,  $q + or + ab + ac + ns$ , which for convenience is termed the Fractionation Index (FI). This expression is merely a modification of the Differentiation Index of Thornton and Tuttle (1960), and reflects the observation of Bailey and Schairer (1964) that peralkaline felsic liquids fractionate not towards petrogeny's residua system but towards eutectics enriched in alkali silicate relative to that system.

The variation diagrams (fig. 3) show that with increasing Fractionation Index there is a regular decrease of MgO, CaO, TiO<sub>2</sub>, and P<sub>2</sub>O<sub>5</sub>, and an overall decrease in FeO+Fe<sub>2</sub>O<sub>3</sub> and MnO. Al<sub>2</sub>O<sub>3</sub> falls steadily from the point where alkali feldspar first occurs as phenocrysts. The distribution of the alkalis is complex and is discussed in detail below. SiO<sub>2</sub> shows an overall increase from 49 to 76 %, but reaches a maximum in the riebeckite microgranites and declines slightly in the aegirine microgranites. The curve shows scarcity of specimens in the range 66–71 % SiO<sub>2</sub>. As only 33 analyses of the dykes have been plotted in fig. 3, it might be argued that the composition gap is the result of insufficient sampling. A histogram for



Fractionation Index =  $\sum$  normative q+or+ab+ac+ns

all Gardar rocks (99 analyses, fig. 4) shows a minimum in the range 70–72 %, suggesting that there may be a significant gap. However, in the case of the rocks from the various central complexes 10 of the samples (between 70–74 %) come from a single member of the Ilímaussaq intrusion (Hamilton, 1964). Of the dyke analyses shown in fig. 4, 35 are from the Tugtutôq area. Any sample bias shown in the Tugtutôq series will obviously strongly bias the form of the histogram. In fact, the microgranites (15 analyses in table 4, pp. 277–278) have been grossly oversampled for analysis compared to the microsyenites (14 analyses in table 4), considering the inferred volume relationships in the area (fig. 1). The histogram gives a completely inaccurate picture of relative volumes of trachytic magma (with  $\text{SiO}_2 > 60\%$ ) and rhyolitic magma, and many more analyses of Gardar acid rocks are needed to establish whether or not the silica-gap really exists.

### Origin of the dyke series

Apart from the alkalis, the major elements show smooth and regular trends in the variation diagrams, and appear, in a qualitative way at least, to be explicable in terms of fractionation of the observed phenocryst minerals from trachytic magma (table 2). An origin by crystal fractionation has already been proposed by Upton (1964 a), by analogy with the rocks of the Kûngnât complex. The Kûngnât trachytic magma is thought to have fractionated as a result of bottom-accumulation of feldspar, olivine, clinopyroxene and ilmenomagnetite to yield a layered series of syenites with peralkaline granitic residua (Upton, 1960). The volume relationships of the trachytic and rhyolitic magmas in the Tugtutôq area, inferred from their relative outcrops (fig. 1), are also consistent with this hypothesis. However, the distribution of Na and K, described below, is not readily explicable in terms of derivation of the series by simple crystal fractionation, mainly due to the fact that the alkali contents of the magmas intruded to form the dykes have probably been affected by several processes other than fractional crystallisation, namely loss of a vapour phase, devitrification, alkali-ion exchange effects and hydrothermal alteration. The present  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios of the dykes cannot therefore be taken as those of the liquids, and the fractionation path (or paths) of the dyke magmas cannot be accurately deduced. The effects of these various processes are described below.

#### Distribution of $\text{Na}_2$ and $\text{K}_2\text{O}$

The behaviour of the alkalis in relation to  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  can conveniently be examined in two projections recently devised by Bailey & Macdonald

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Fig. 3. Variation diagram for the dykes, using Fractionation Index as abscissa (see text for explanation). Crosses – trachydolerites, triangles – hastingsite microsyenites, squares – riebeckite microsyenites, closed circles – riebeckite microgranites, open circles – aegirine microgranites.

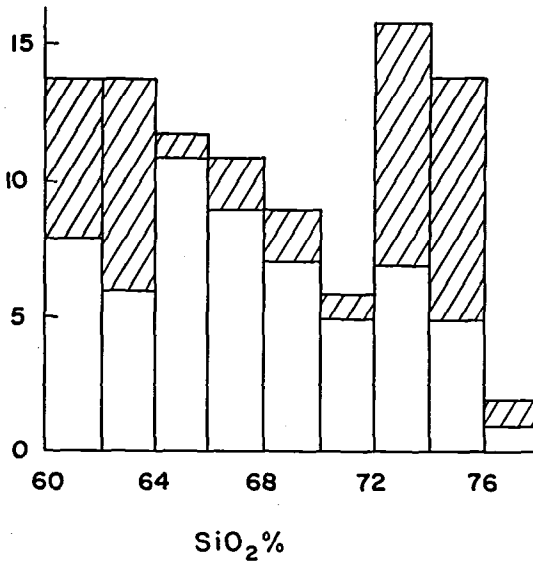


Fig. 4. Frequency of  $\text{SiO}_2$  values in Gardar alkaline rocks having  $\text{SiO}_2 > 60\%$ . Blank columns - central complexes, striped columns - dyke swarms. Data from Upton (1960), Hamilton (1964), Watt (1966), this paper (table 4), and Macdonald (unpublished data).

(1969). The first of these (fig. 5 a) is a simple triangular diagram plotting molecular  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  against  $(\text{Na}_2\text{O} + \text{K}_2\text{O})$ . The alkali feldspar compositional join plots as a point, and any plane radiating from that join projects as a line. For example, Or-Ab-P''-P' is a plane in the peralkaline oversaturated volume of the system  $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$  (fig. 5 b) and it is represented in fig. 5 a by the line Feldspar - P'P''. A deficiency of this projection is that it cannot be used to show the alkali ratio of rocks. The conventional granite system, Q-Or-Ab, does not share this deficiency, but is of limited value in plotting the compositions of peralkaline rocks as it assumes a 1 : 1 ratio of alkalis : alumina (Bailey & Schairer, 1964, Thompson & Mackenzie, 1967). The ratio  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  can, however, be shown in projection on planes such as Or-Ab-P''-P' (fig. 5 c), since lines of constant  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio can be drawn crossing the plane. Trends in magma series can be shown in terms of decreasing  $\text{Al}_2\text{O}_3$  and correct alkali ratio. Feldspar compositions and tie-lines to rocks can also be shown.

An important feature that can be demonstrated using a  $\text{SiO}_2-\text{Al}_2\text{O}_3$ -alkalis diagram (fig. 6) is that fractionation of alkali-feldspar alone from any slightly peralkaline oversaturated liquid (e.g. X) must drive the residual liquid towards feldspar-poorer compositions along the projection of F-X, i.e. towards X'. With further feldspar fractionation the liquid will persist along the projection of F-X until another process intervenes, such as crystallisation of another phase. For example, fractionation of quartz is



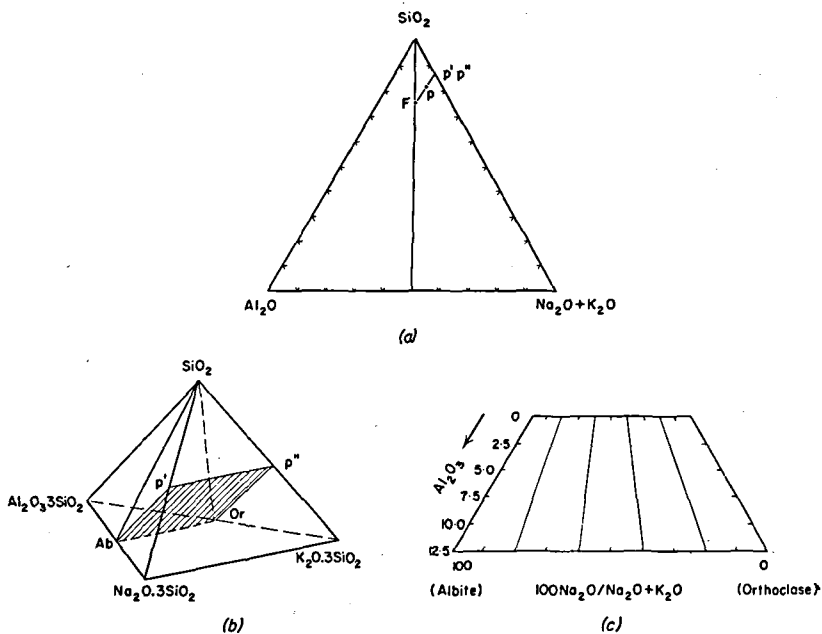


Fig. 5. (a)  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-(Na}_2\text{O+K}_2\text{O)}$  diagram. F = alkali feldspar. P = hypothetical peralkaline composition. P'P'', the intersection of F-P on the alkali-silica sideline, measures the alkali-silica index of composition P. (b) The oversaturated volume of the system  $\text{Na}_2\text{O-K}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2$ , showing the plane Ab-Or-P''-P'. This plane is equivalent to F-P-P'P'' in (a). (c) Quadrilateral representing any plane in the peralkaline volume of (b), such as Ab-Or-P''-P'.

possible when the quartz-feldspar cotectic is reached. In fig. 6 have been plotted the quartz-potash feldspar (K-K') and quartz-albite (N-N') cotectics from the system  $\text{K}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2$  and  $\text{Na}_2\text{O-Al}_2\text{O}_3\text{-SiO}_2$  both at 1 atmosphere (Schairer & Bowen, 1955 and 1956). The cotectic relevant to the Tugtutôq dyke series is chemically restrained into the zone defined by K-K' and N-N', and the fractionation trend must be within that zone, i.e. at a large angle to any earlier fractionation path.

The Tugtutôq peralkaline dykes lie on a trend initially similar to F-X-X', but the microgranites show a clustering around 85 % silica, the aegirine microgranites lying further down the quartz-feldspar cotectic zone, i.e. at  $\text{SiO}_2$ - and  $\text{Al}_2\text{O}_3$ -poorer positions, than the riebeckite microgranites (fig. 7). This trend is consistent with fractionation of feldspar in the microsyenites followed by feldspar plus quartz fractionation in the microgranites, i.e. by removal of the most abundant phenocryst phases.

In detail, the trend of the hastingsite microsyenites in fig. 7 does not pass on extrapolation through the alkali feldspar composition, but some point slightly richer in  $\text{Al}_2\text{O}_3$ . This probably reflects the operation of the pla-

gioclase effect of Bowen (1945) and is a measure of the amount of Al associated with Ca in the feldspar phenocrysts.

The plagioclase effect is potentially feasible in any magmas containing normative diopside. The trachydolerites and hastingsite microsyenites of Tugtutôq suite all carry this normative constituent. The feldspar phenocrysts from 50226, a non-peralkaline hastingsite microsyenite, carry appreciable amounts of anorthite molecule, 7 % by weight (Upton, 1964 a), and those from Gardar microsyenite dykes reported by Scharbert (1966) up to 14 % An by weight. Fractionation of such feldspars could result in fractionally removing  $\text{Al}_2\text{O}_3$  relative to alkalis.

In the peralkaline dykes, the effect of Ca-entry into the feldspars is greatly diminished, and there is usually less Ca in the phenocrysts than in the rock. However, in such  $\text{Al}_2\text{O}_3$ -deficient compositions, the fractionation of any feldspar will accentuate the peralkalinity, and the plagioclase effect must still be considered operative.

The Tugtutôq peralkaline dyke rocks have been plotted in fig. 8, with tie-lines to their respective feldspar phenocrysts. There is an irregular, but strong increase in  $\text{Na}_2\text{O}/\text{Na}_2\text{O}+\text{K}_2\text{O}$  ratio from the hastingsite microsyenites to the riebeckite microsyenites, but a regular decrease in progressively more acid dykes. It is clear from the attitude of the feldspar/rock tie-lines, however, which show that the phenocrysts are in all cases more potassic relative to soda than the whole rocks, that fractionation of feldspar

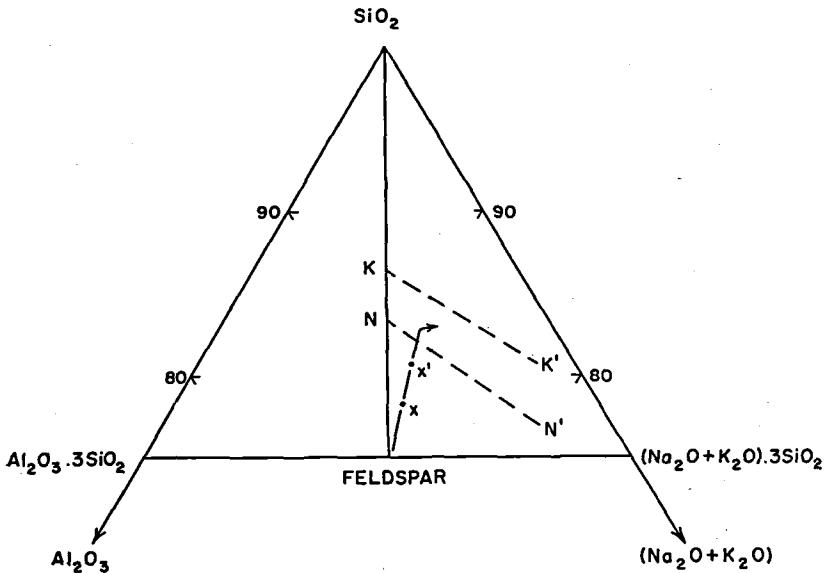


Fig. 6.  $\text{SiO}_2$ - $\text{Al}_2\text{O}_3$ -( $\text{Na}_2\text{O}+\text{K}_2\text{O}$ ) diagram, in which have been plotted the quartz-albite (N-N') and quartz-potash feldspar (K-K') experimental cotectics at 1 atmosphere. A possible fractionation path of a peralkaline trachyte (X) is shown.

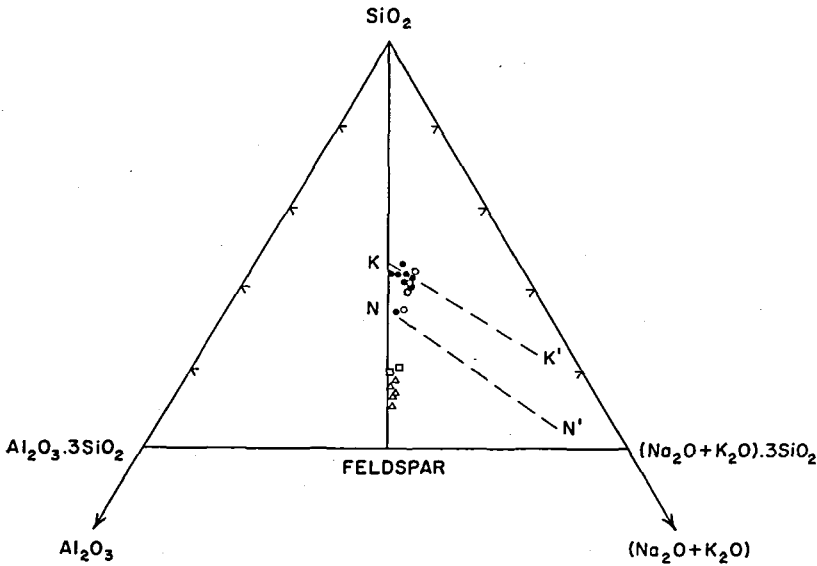


Fig. 7. Analyses of Tugtutôq peralkaline dykes in a  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-(Na}_2\text{O+K}_2\text{O)}$  diagram. Symbols as in fig. 3.

(± quartz) should at all stages produce residual liquids enriched in soda. The trend towards decreasing  $\text{Na}_2\text{O}/(\text{Na}_2\text{O} + \text{K}_2\text{O})$  ratio in the microgranites cannot therefore be a result of simple feldspar (± quartz) fractionation, although the distribution of the analyses in the  $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-(Na}_2\text{O} + \text{K}_2\text{O)}$  diagram (fig. 7) was consistent with this origin.

If the analyses of the dykes are taken to represent original liquid composition, and if the chemical variation in the series is a result solely of crystal fractionation, then the trend of alkali ratios in the microgranites must be a result of fractionation of another alkali-bearing phase with feldspar, one rich in Na relative to K, and poor in Al. The only mineral in the phenocryst assemblage of the riebeckite microgranites is riebeckite-arfvedsonite, which if removed in sufficiently large amounts relative to feldspar could result in lowered  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios of residual liquids. However, the amphibole phenocrysts are present in the dykes in only very minor amounts compared to the feldspar phenocrysts (table 3, pp. 275–276) and any effect of fractionating amphibole must have been slight compared to that of feldspar crystallisation. Furthermore, the trend in the microgranites is towards enrichment in normative acmite (table 5, pp. 279–280), whereas fractionation of large amounts of riebeckite-arfvedsonite could initiate a miaskitic from a peralkaline trend. The riebeckite-arfvedsonite phenocrysts in the Tugtutôq dykes commonly enclose magnetite, and, although magnetite phenocrysts are common in the more basic rocks, they are generally absent in the most acid dykes, suggesting that there is a reaction relationship between magnetite and liquid to produce amphibole. It is likely that

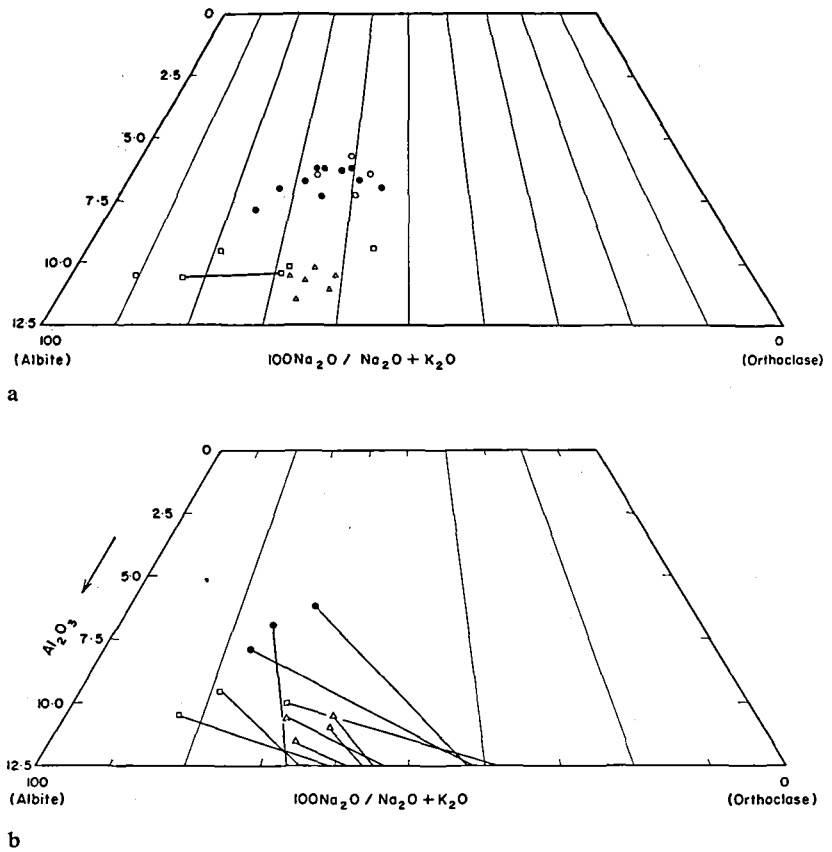


Fig. 8. (a) Analyses of Tugtutôq peralkaline dykes plotted in a quadrilateral representing a plane in the volume  $\text{Na}_2\text{O}-\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$  such as Ab-Or-P'-P' in fig. 5b. Symbols as in fig. 3. Heavy line joins the margins (50050) and centre (50051) of a riebeckite microsyenite dyke. (b) Same plot, with compositions of dykes tied to their feldspar phenocrysts (in terms of Or/Or + Ab mol. per cent).

magnetite fractionated from those peralkaline rhyolites during magma ascent, but that amphibole commenced crystallisation giving phenocrysts only at high crustal levels, shortly before final emplacement and consolidation of the dykes. A comparable situation is found in the Kûngnât complex (Upton, 1960), where there is some evidence from magnetite-rich schlieren in the riebeckite granites, that while magnetite acted as an accumultic phase, there is no direct evidence that riebeckite-arfvedsonite ever behaved similarly.

It is suggested that the alkali distribution in the acid dykes cannot be explained simply in terms of fractionation of the observed phenocryst assemblages. Several alternative processes may now be considered.

### Loss of vapour phase

Where the vapour pressure in a magma exceeds the external pressure, a volatile phase will separate, which may or may not be above its critical point, depending on the type and amount of solutes in it (Krauskopf, 1967). The critical point of water is lowered by the addition of solutes of greater volatility, but raised by involatile elements. In the first case, the volatile phase may remain above its critical point until after consolidation of the magma, and the maximum number of fluid phases is two. In case two, the separating phase may be rich in dissolved salts (geological evidence such as liquid inclusions and volcanic emanations indicates that NaCl is especially common) and may fall below its critical point, where yet another fluid phase may separate, richer in water and halogens. A natural example of this second case has been described by Roedder & Coombs (1967), working on fluid inclusions in peralkaline granites from Ascension Island. Great importance attaches to these dense, supercritical fluids, because they are strong solvents and are a potent mechanism for removing Na and to a lesser extent K from silicate melts.

It is possible that the magmas which formed the Tugtutôq dyke series underwent continuous loss of a supercritical vapour phase during their ascent and emplacement. Further, if it is assumed that volatiles were enriched in residual liquids during fractionation, then the volatile pressure may have been sufficiently high to allow escape of a vapour phase only in the rhyolitic magmas. If this fugitive fluid phase contained a high proportion of Na relative to K, then the process could have had the effect of decreasing the  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios determined by fractional crystallisation. Unfortunately, it is impossible to make even qualitative estimates of the alkalis lost during this process.

### Loss of alkalis on magmatic crystallisation or devitrification

The vapour phase discussed above was that separating from the essentially liquid magma during its ascent and emplacement. A further fluid phase may escape from the cooling magma – during magmatic crystallisation, or in the case of magma chilled to a glass, during subsequent devitrification. In these latter cases, the magma may be considered essentially solidified.

There is much recent evidence on the chemical changes affecting peralkaline acid lavas during magmatic crystallisation or devitrification (Carmichael, 1962; Noble, 1965, 1967; Noble, Smith and Peck, 1967; Ewart, Taylor and Capp, 1968). The most marked effects are loss of alkalis, especially Na, and halogens, but Al may be gained and Si gained or lost. The alkalis lost in this way are those left after feldspar plus aegirine (or amphibole) formation, i.e. those normally expressed as normative sodium metasilicate. Noble (1965), for example, found that more than one-quarter of the  $\text{Na}_2\text{O}$  originally present in a pantellerite tuff was lost on devitrification.

It is clear that the alkalis : alumina : silica ratios in the Tugtutôq dykes cannot safely be assumed to be those of the liquids immediately prior to solidification, and that late-stage alkaline fluids probably escaped from the

dykes, presumably also enriched in halides and water. There is unfortunately no indication of where they have escaped to, as there is no evidence of wall-rock contamination. One must assume that these residual fluids streamed up the dykes and were lost to the surface, or alternatively that they were removed at a much later stage by groundwater leaching. That alkali loss has been operative in at least some of the peralkaline Gardar intrusives is shown by the alkali metasomatism of wall-rocks seen in the intrusive complexes at Kûngnât, Ilímaussaq and central Tugtutôq.

The feldspar phenocrysts of the peralkaline Tugtutôq dykes all have lower ratios of  $\text{Na}_2\text{O}/\text{Na}_2\text{O} + \text{K}_2\text{O}$  than the host rocks, suggesting operation of the orthoclase effect (Bailey & Schairer, 1964). Successive residual liquids after feldspar fractionation should contain larger amounts of excess alkalis with increasing  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio. On devitrification, progressively larger amounts of Na should be lost relative to K, and the result could be that the rock series showed a trend of decreasing  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio in more acid dykes (fig. 8).

One effect of devitrification would be to cause a scatter of analyses of acid dykes in the  $\text{SiO}_2$ - $\text{Al}_2\text{O}_3$ -alkalis diagram (fig. 7). Alkali loss will tend to drive the projected *liquid* compositions away from the alkali apex and towards the  $\text{Al}_2\text{O}_3$ - $\text{SiO}_2$  side-line. Since more acid dykes always show increasing proportions of aegirine : feldspar (table 5), despite devitrification, the composition trend can never cross to the  $\text{Al}_2\text{O}_3$ -rich side of the  $\text{Al}_2\text{O}_3$  : alkalis = 1 : 1 line i. e. to a miaskitic trend, as a result of this process.

#### Alkali-ion exchange effects

A further complication to the alkali balance is that unequal distribution of Na and K in various parts of the same dyke may be common, especially between chilled margins and coarser centres. The only available data are for the riebeckite microsyenite, 50050 (chill) and 50051 (centre). The zones have similar total alkali contents (9.7 % and 10.4 % respectively), but different  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios, 3.25 and 1.48 by weight. It is unlikely that the zones in this dyke represent different pulses from magma body differentiated prior to intrusion because the bulk chemistry of chill and centre are almost identical, apart from alkalis (table 4). The data are consistent, however, with exchange of alkali ions across the dyke, presumably migrating along a temperature gradient during the cooling of the dyke. The two compositions are joined by a heavy line in fig. 8 a and there is a marked difference in plotted position. Many more analyses are required to determine whether this situation is general, but it may mean that the distribution of points in fig. 8 is partly a result of sampling within the dykes, and further work may modify the trends quite considerably.

#### Loss of Na on alteration of amphibole

There is evidence that alteration of soda-amphibole can lead to decreased  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios in the Tugtutôq dykes. In the large composite micro-

granite dyke which extends through central Tugtutôq (Upton, 1964, p. 16–17) two main acid facies are present: a normal riebeckite-arfvedsonite bearing variety, and a more oxidised variety, in which haematite is the sole coloured mineral. There are transitional types, with amphibole largely replaced by magnetite. The  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios of oxidised and normal facies are 0.65 and 0.73 respectively. Locally, presumably attendant upon high oxidation conditions, magnetite and finally haematite became the stable Fe-bearing mineral rather than amphibole. Na must have been released during this oxidation, possibly to the wall-rock, and the normative result was the appearance of a small amount (0.8 %) of corundum (table 7).

Whereas such a small amount of normative corundum could be due to analytical error, the analysis of a porphyritic rhyolite sill from the south side of the Narssaq valley (GGU 61848, table 7, p. 281) which Upton (1962, p. 36) suggested could have been fed by the Tugtutôq dyke, also contains normative corundum (1.2 %). The sill has similar chemistry to the dyke and it seems likely that the excess of Al is real.

The riebeckitic facies of this big dyke is itself relatively alkali-deficient, and despite the presence of soda-iron amphibole it contains a small amount of normative anorthite (2.2 %). The appearance of corundum on alteration of the amphibole is to be expected only from dykes containing low potential acmite, but the process can affect  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios in more strongly peralkaline dykes. The alteration of amphibole to limonite in the Tugtutôq microsyenites has probably resulted in a decrease in Na/K ratios, and may explain, at least in part, the spread of points in the lower part of fig. 8.

#### Divergence of fractionation trends

The evidence of possible alkali migration in the riebeckite microsyenite dyke 50050/50051 suggests that the high Na contents of some of these dykes may be a post-intrusion effect. It is assumed here, for sake of discussion, that the high  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios of certain of the riebeckite microsyenites is a primary feature of the magmas. Since the feldspar phenocrysts in the dykes are always more potassic than the liquids, feldspar fractionation alone would tend to produce progressively more sodic residual liquids. Since the riebeckite microsyenites have  $\text{Na}_2\text{O}/\text{Na}_2\text{O} + \text{K}_2\text{O}$  ratios of up to 90 %, it is clear that the rhyolite magmas would have been enriched in Na almost to the exclusion of K by this process. In a literature survey of all peralkaline acid lavas, the author was unable to find a description of a suite of rocks so enriched in Na relative to K. It seems doubtful that the highly sodic riebeckite microsyenites could have been parental to the microgranites, even assuming loss of large amounts of Na from the rhyolite magmas in residual fluid phases during consolidation and/or subsequent devitrification.

An alternative solution may be that microgranites have been derived from a hastingsite microsyenite stem with low  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratio (e.g. 50169, table 4), and that the Na-rich riebeckite microsyenites represent a separate evolutionary branch. Some support for this is found in the feldspar phenocryst compositions.

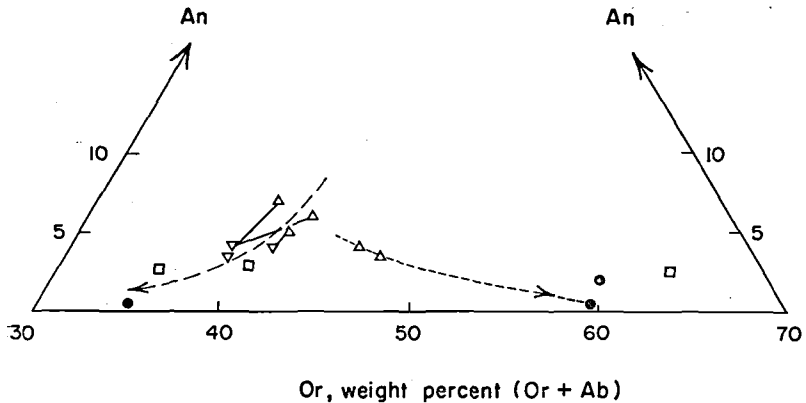


Fig. 9. Part of an Or-Ab-An diagram. Triangles - feldspar phenocrysts from hastingsite microsyenites (inverted = groundmass feldspars), squares - from riebeckite microsyenites, circles - from riebeckite microgranites. Tie-lines connect phenocryst and groundmass feldspars from same rock. Inferred trends towards Ab- and Or-enrichment are shown by dashed lines. Data from this paper and from Upton (1964a).

The gabbroic and syeno-gabbroic intrusions of Tugtutôq show a range in feldspar composition from circa  $An_{70}Ab_{30}$  through K-rich oligoclase to Ca-bearing alkali feldspar (Upton, 1964b). There is no clear evidence that two feldspars were coprecipitating at any stage; a single continuous feldspar sequence is observed with a change from triclinic to monoclinic symmetry inferred at approximately  $Or_{20-25}$ .

The trend shown by the feldspar phenocrysts of the hastingsite microsyenite dykes of Tugtutôq is towards Or-enrichment at the expense of Ab and An (fig. 9), and strong K-enrichment is also shown in two of the microgranites ( $Or_{50}$ ). The feldspars of the riebeckite microsyenites do not lie on this trend; whereas two plot at more sodic compositions, one has the maximum Or content ( $Or_{62}$ ) of any of the analysed feldspars. The feldspars from a third microgranite, 50187, has the lowest Or-content of any analysed specimen ( $Or_{35}$ ). The behaviour of the feldspar phenocrysts is therefore not simple, and once again an origin of the dyke series by continuous crystal fractionation must be questioned. There is, however, some support for the idea that there has been a divergence in the hastingsite microsyenites towards, on the one hand, the riebeckite microsyenites and on the other, the microgranites. Where data are available, the groundmass feldspars of the hastingsite microsyenites are slightly enriched in Ab relative to the phenocrysts (Upton, 1964 a). It is therefore possible to group these feldspar phenocrysts with those of the riebeckite microsyenites into a series showing Ab-enrichment with decreasing An-content, and to link the other two hastingsite microsyenites with the microgranites (fig. 9). This theory leaves unexplained the anomalously high and low Or contents of the microsyenite 50167 and the microgranite 50187 respectively, but has the



advantage of being open to test; the groundmass feldspars of the micro-syenite dyke 50169 should be slightly richer in Or than the phenocrysts.

If this divergence is accepted, it is a short step to viewing the series as comprising a large number of separate trends, or "bundle of liquid lines of descent", only approximating a single fractionation series. This effect has been termed "proliferation of liquid lines of descent" by Cox (1967). Consider a basaltic magma ascending through the crust, crystallising on a cotectic equilibrium. If it ascends reasonably slowly, the magma may never leave the cotectic condition, that is crystallisation may keep pace with the changing pressure conditions. In this case, the magma gives rise to a series of residual liquids which define a unique fractionation trend. During rapid magma ascent, however, involving sudden changes of pressure, the magmas may leave the higher pressure cotectic equilibria and pre-existing phenocrysts will tend to be resorbed. Under the new pressure-temperature conditions, different phenocryst assemblages will separate, and each member of the original series of magmas can itself be parental to a series of derivatives. Crystal/liquid processes tend to drive a fairly wide range of basic liquids towards similar end-points on fractional crystallisation. The residua produced by the proliferated magma series may therefore be compositionally very similar, and it may prove impossible to tell that they had had rather different evolutionary histories. The dyke magmas intruded in the large Gardar province were derived from several batches supplied over long periods of time, and the assumption made earlier that they can be considered as a single petrochemical series was perhaps naive.

## Conclusions

There is reasonable evidence from various sources that the Tugtutôq acid dykes were formed from trachytic magmas dominantly by fractionation of alkali feldspar, accompanied by quartz in the rhyolites. However, the  $\text{Na}_2\text{O}/\text{K}_2\text{O}$  ratios of the original magmas have probably been modified by several processes, including loss of a vapour phase, devitrification, alkali-ion exchange effects and secondary alteration of amphibole. It is thus impossible to describe closely the evolutionary trend (or trends) of the magmas. Further, the dykes were intruded as a number of swarms over a considerable period of time, and probably did *not* initially represent a single evolutionary sequence.

The study of all crystalline peralkaline rocks is open to the problems of interpretation met during this work, and answers to the problems of the petrogenesis of peralkaline magmas must be sought in glassy lavas.

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## Appendix

### Methods of analysis

The rock samples were analysed for Si, Ti, Al, Fe, Mn, Mg and Ca by X-ray fluorescence spectroscopy, using Philips XRF equipment (PW 1310/50 generator with PW 1320 control cabinet). The rock powder was diluted with  $\text{La}_2\text{O}_3$  and  $\text{Li}_2\text{B}_4\text{O}_7$  in order to minimise matrix absorption effects, fused, crushed and briquetted using boric acid as a binder. Calibration curves were drawn up for each element using the international rock standards (G1, W1, S1 etc.). Na and K were determined by flame photometer, P by spectrophotometer, and Fe<sup>3+</sup> by titration with dichromate.  $\text{H}_2\text{O}$  was determined gravimetrically, and F by the spectrophotometric method of Peck and Smith (1964, *Talanta*, Vol. 11, 1343–1347).

In the feldspar samples, Na and K were determined by flame photometer, Ca by titration with EDTA, and Fe (as  $\text{Fe}_2\text{O}_3$ ) by titration with  $\text{K}_2\text{Cr}_2\text{O}_7$ , using the  $\text{SnCl}_2$  reduction technique recommended by Mercy & Saunders (1966, *Earth Planet. Sci. Letters*, Vol. 1, 169–182).

## Dansk sammendrag

Intermediære til sure alkaline gange af Gardar alder fra Tugtutôqområdet i Sydgrønland danner en næsten fuldstændig serie fra trakydoleriter over hastingsit- og riebeckitbærende mikrosyeniter til riebeckit- og ægirinmikrograniter. Kemisk viser serien en overgang fra anortit- og nefelin-normative typer til acmit- og kvarts-normative typer. Selvom gangene antages oprindeligt at være afledt fra basaltisk magma ved fraktionering, har flere processer tjent til at ændre den oprindelige væskesammensætning, heri medregnet tab af en dampfase, afglasning af sure gange, udbygning af alkaline ioner og omdannelse af amfibol. Mønsteret for magmaernes udvikling kan derfor ikke fastlægges nøjagtigt.

Table 3. Modes of analysed specimens.

	Trachydolerites				Hastingsite microsyenites				Riebeckite microsyenites									
	40471	50093	50149		30713	40429	40433	40462	40498	40570	50169	50226	30645	30739	50050	50051	50136	50167
Phenocrysts																		
Feldspar.....	-	-	-	-	32.2	30.0	12.1	16.2	26.2	5.4	25.2	24.6	18.0	-	tr.	tr.	10.5	16.4
Quartz.....	-	-	-	-	0.1	tr.	-	tr.	tr.	-	-	-	-	-	-	-	-	-
Apatite.....	tr.	-	tr.	-	0.2	tr.	-	tr.	tr.	-	-	0.2	0.3	-	-	-	-	-
Ore.....	-	-	-	-	-	-	-	0.8	tr.	-	-	-	-	-	-	1.6	-	-
Olivine.....	-	-	-	-	-	-	-	-	tr.	-	-	0.6	-	-	-	-	-	-
Pyroxene.....	-	-	-	-	-	-	0.1	-	-	tr.	tr.	0.6	-	-	-	-	-	-
Amphibole.....	-	-	-	-	-	-	-	-	-	-	0.6 <sup>1</sup>	-	-	-	-	-	-	-
% phenocrysts.	-	0.0	-	32.5	30.0	12.2	17.0	26.2	26.2	5.4	25.8	26.0	18.3	0.0	1.6	0.0	10.5	16.4
Groundmass																		
Feldspar.....	60.6	64.1	73.6	44.5	49.1	58.7	56.8	53.3	68.9	51.9	52.1	-	-	-	51.1	70.0	40.3	40.4
Quartz.....	-	-	-	-	-	0.6	2.7	tr.	tr.	1.9	4.5	-	-	-	tr.	0.8	-	-
Apatite.....	1.9	-	0.9	-	tr.	-	-	-	tr.	-	-	-	-	-	-	-	-	-
Ore.....	7.1	5.1	6.2	0.9	1.9	1.9	1.5	1.6	2.0	0.3	-	-	-	-	4.6	5.2	-	0.4
Biotite.....	20.7	1.8	9.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyroxene.....	9.7	8.2	8.4	-	5.5	tr.	-	-	-	-	-	-	-	-	-	-	-	-
Amphibole.....	-	-	-	{6.61}	{5.4}	{18.7}	{11.31}	{14.9}	{16.8}	{16.8}	{8.9}	-	-	-	41.8	22.8	42.1	42.2
Limonite.....	-	-	-	{6.02}	8.0	4.9	3.9	4.0	5.0	0.7	13.0	-	-	-	0.9	1.2	7.1	-
Zircon.....	-	-	-	1.4	-	tr.	-	-	tr.	-	-	-	-	-	-	-	-	0.6
Carbonate.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluorite.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vugs.....	-	-	-	-	2.0	-	-	-	-	-	-	-	0.3	-	-	-	-	-
% groundmass.	100.0	79.2	98.7	67.4	70.0	87.8	82.9	73.8	94.6	74.2	74.0	74.0	81.7	100.0	98.4	100.0	89.5	83.6

1 = hastingsite, 2 = riebeckite-afvedsonite. 50093 - plus chlorite (16.6%) and epidote (4.2%), 50149 - plus chlorite (1.3%).

Table 3 (contd.)

	Riebeckite microgranites										Aegirine microgranites				
	30685	30758	40427	40449	40493	40495	40575	50163	50181	50187	50237	30691	40554	40600(g)	50197
Phenocrysts															
Feldspar.....	4.3	-	18.0	2.2	3.7	17.6	10.6	-	18.1	20.0	-	4.1	8.4	20.3	16.1
Quartz.....	5.2	-	8.7	4.1	1.4	17.0	9.4	-	10.9	14.0	tr.	4.4	2.3	20.2	4.5
Apatite.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ore.....	-	-	-	tr.	-	-	2.5	2.6	-	-	-	-	-	-	-
Olivine.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pyroxene.....	-	-	-	-	-	1.9	1.5	-	-	-	-	tr.	0.2	tr.	1.2
Amphibole....	-	-	0.8	-	0.8	tr.	-	-	3.6	-	-	tr.	-	tr.	-
% phenocrysts.	9.5	0.0	27.5	6.3	5.9	36.5	23.0	2.6	32.6	34.0	0.0	8.5	10.9	40.5	21.8
Groundmass															
Feldspar.....	64.5	51.1	33.0	45.5	46.0	33.0	51.0	-	33.3	-	48.9	52.3	41.5	-	27.2
Quartz.....	-	-	24.0	26.2	27.8	16.5	-	-	22.2	-	32.6	-	-	-	22.3
Apatite.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ore.....	-	tr.	tr.	3.8	-	-	-	-	0.9	-	tr.	-	-	-	1.3
Biotite.....	-	-	-	-	-	-	-	-	-	-	tr.	-	-	-	-
Pyroxene.....	15.9	27.7	3.9	-	6.7	12.0	-	-	tr.	-	-	39.2	42.6	-	26.1
Amphibole....	9.8	21.2	11.5	17.2	12.8	1.5	24.8	-	11.0	-	18.5	-	3.9	-	-
Limonite.....	-	-	-	1.0	-	-	-	-	-	-	-	-	-	-	1.3
Zircon.....	-	-	-	-	-	-	0.7	-	-	-	tr.	-	-	-	-
Carbonate.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluorite.....	0.3	-	-	-	-	-	-	-	-	-	tr.	-	-	-	-
Vugs.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
% groundmass.	90.5	100.0	72.4	93.7	93.3	63.0	77.0	97.4	67.4	66.0	18.5	91.5	89.1	59.5	78.2

40495 - plus pyrochlore? (0.5%).

Table 4. Analyses of dykes from the Tugtutóq area

	Trachydolerites			Hastingsite microsyenites					Riebeckite microsyenites								
	40471	50093	50149	30713	40429	40433	40462	40498	40570	50169	50226	30645	30739	50050	50051	50138	50167
SiO <sub>2</sub> .....	49.2	51.6	54.4	61.1	59.1	61.1	62.1	62.9	62.5	63.8	60.4	66.0	63.8	62.2	62.3	64.2	65.2
TiO <sub>2</sub> .....	2.49	1.91	1.70	0.83	1.15	1.00	0.96	0.98	0.94	0.65	0.98	0.67	0.90	0.76	0.66	0.73	0.66
Al <sub>2</sub> O <sub>3</sub> .....	15.40	16.30	15.30	15.60	16.34	14.20	13.60	15.30	14.30	14.53	16.55	13.50	14.60	14.30	14.00	12.87	13.95
Fe <sub>2</sub> O <sub>3</sub> .....	3.20	2.92	5.93	2.61	4.13	2.68	3.18	2.33	1.78	2.81	2.66	4.04	3.35	4.44	5.08	3.57	2.95
FeO.....	8.93	7.90	5.48	4.36	3.44	5.82	5.35	4.43	5.69	4.04	3.91	4.73	5.27	4.96	4.16	4.18	5.13
MnO.....	0.19	0.22	0.20	0.20	0.15	0.20	0.22	0.16	0.19	0.15	0.17	0.19	0.19	0.24	0.21	0.19	0.21
MgO.....	2.56	2.29	1.03	0.41	0.67	0.38	0.24	0.40	0.35	0.23	0.63	0.14	0.25	0.05	0.04	0.00	0.02
CaO.....	5.54	5.05	3.62	2.19	2.32	1.96	2.18	1.51	1.89	1.61	1.87	1.09	1.68	1.68	1.58	1.21	1.58
N <sub>2</sub> O.....	4.58	4.93	4.86	6.16	5.19	6.02	5.66	5.89	6.24	5.54	5.36	7.15	8.65	7.42	6.19	4.93	5.89
K <sub>2</sub> O.....	3.60	3.43	4.25	4.82	5.31	4.78	4.80	5.54	4.54	5.34	5.84	2.92	1.39	2.28	4.18	6.03	4.18
P <sub>2</sub> O <sub>5</sub> .....	1.24	0.74	0.71	0.15	0.34	0.18	0.15	0.35	0.18	0.13	0.29	<0.05	0.13	0.09	0.15	0.06	0.08
H <sub>2</sub> O <sup>+</sup> .....	1.17	1.66	1.50	0.56	0.86	0.45	0.46	0.60	0.48	0.29	0.78	0.45	0.42	0.48	0.28	0.59	0.36
F.....	0.18	0.12	0.12	0.10	0.09	0.15	0.18	0.12	0.20	0.14	0.09	0.18	0.03	0.23	0.26	0.11	0.19
O ≡ F.....	98.28	99.07	99.10	99.09	99.09	98.92	99.08	100.51	99.28	99.26	99.53	101.06	100.66	99.13	99.09	98.67	100.40
Total.....	0.08	0.05	0.05	0.04	0.04	0.06	0.00	0.05	0.08	0.06	0.04	0.07	0.01	0.10	0.11	0.05	0.08
F. I.....	98.20	99.02	99.05	99.05	99.05	98.86	99.00	100.46	99.20	99.20	99.49	100.99	100.65	99.03	98.98	98.62	100.32
F. I.....	53.9	57.7	68.6	82.3	79.0	81.5	82.1	86.0	83.2	85.9	85.0	87.5	85.0	83.0	84.7	88.7	85.0

F. I. = Fractionation Index, Σ norm q + or + ab + ac + ns; 50136, 50187, 50226 - from Upton (1964a), except for F; 50136 - Cu<sub>2</sub> = 1.14%; 50226 - CO<sub>2</sub> = 0.44%.

Table 4 (contd.)

	Riebeckite microgranites										Aegirine microgranites				
	30685	30758	40427	40449	40493	40495	40575	50163	50181	50187	50237	30691	40554	40600(a)	50197
SiO <sub>2</sub> .....	71.5	73.7	74.4	72.5	75.3	74.6	75.8	72.7	75.6	75.9	74.6	75.7	73.9	73.1	74.6
TiO <sub>2</sub> .....	0.43	0.42	0.19	0.65	0.36	0.18	0.40	0.35	0.43	0.32	0.45	0.36	0.34	0.42	0.21
Al <sub>2</sub> O <sub>3</sub> .....	11.50	9.28	10.00	10.95	9.15	9.35	10.55	9.06	10.10	10.47	11.00	9.70	9.65	10.90	8.45
Fe <sub>2</sub> O <sub>3</sub> .....	3.42	4.14	2.55	3.77	3.02	4.84	3.44	4.96	2.32	2.27	2.63	4.45	4.57	4.31	5.86
FeO.....	2.16	2.25	2.65	2.10	2.59	0.41	1.90	2.19	2.01	2.44	2.94	0.27	0.58	1.12	0.13
MnO.....	0.14	0.12	0.10	0.08	0.08	0.10	0.07	0.13	0.11	0.07	0.09	0.06	0.08	0.10	0.09
MgO.....	0.06	0.03	0.00	0.51	0.00	0.02	0.00	0.04	0.07	0.00	0.10	0.00	0.00	0.05	0.19
CaO.....	0.34	0.10	0.09	1.59	0.12	0.05	0.21	0.34	0.48	0.29	0.43	0.24	0.29	0.15	0.18
Na <sub>2</sub> O.....	5.99	4.55	5.05	3.22	4.17	5.40	3.65	4.92	4.14	5.04	4.48	4.55	5.36	5.01	4.67
K <sub>2</sub> O.....	2.91	4.19	3.50	4.39	4.19	4.08	4.50	3.86	4.38	2.71	3.66	5.11	4.04	5.17	4.53
P <sub>2</sub> O <sub>5</sub> .....	<0.05	0.10	0.05	0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.07	<0.05	<0.05	<0.05	<0.05
H <sub>2</sub> O <sup>+</sup> .....	0.48	0.22	0.19	0.82	0.16	0.10	0.21	0.15	0.19	0.26	0.07	0.21	0.05	0.39	0.08
F.....	0.20	0.08	0.26	0.41	0.16	0.16	0.11	0.52	0.17	0.20	0.25	0.15	0.29	0.25	0.08
O ≡ F.....	99.13	99.18	99.03	101.11	99.30	99.29	99.78	99.22	100.00	99.97	100.77	100.80	99.15	100.97	99.07
Total.....	99.05	99.15	98.92	100.94	99.23	99.20	99.73	99.00	99.93	99.89	100.66	100.74	99.03	100.86	99.04
F. I.....	92.8	93.9	93.3	88.0	93.8	97.8	94.7	93.6	94.5	94.0	92.6	99.3	97.1	97.4	97.7

Table 5. CIPW norms of analyses of dykes. 50136, 50187, 50226, from Upton (1964a).

	Trachydolerites					Hastingsite microsyenites					Riebeckite microsyenites						
	40471	50093	50149	30713	40429	40433	40462	40498	40570	50169	50226	30645	30739	50050	50051	50136	50167
Quartz.....	-	-	2.7	2.0	3.9	2.8	6.5	3.7	4.1	7.7	3.0	10.9	4.1	7.1	8.4	10.7	10.9
Orthoclase.....	21.1	20.0	25.0	28.4	31.1	28.4	28.4	32.8	26.7	31.7	35.6	17.2	8.3	13.3	24.5	36.4	24.5
Albite.....	32.8	37.7	40.9	51.9	44.0	46.1	43.0	47.7	48.2	45.1	46.4	52.9	67.1	60.8	48.7	33.2	48.7
Anorthite.....	10.8	12.2	7.5	0.8	5.6	-	-	-	-	-	4.0	-	-	-	-	-	-
Na <sub>2</sub> SiO <sub>3</sub> .....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Acmite.....	-	-	-	-	-	4.2	4.2	1.8	4.2	1.4	-	6.5	5.5	1.8	3.2	8.0	0.9
Wollastonite	3.5	3.4	2.4	3.5	1.4	3.2	3.6	2.1	2.9	2.6	-	1.6	3.0	2.4	2.1	2.7	2.7
Enstatite.....	1.4	1.3	1.2	0.6	0.8	0.4	0.3	0.4	0.3	0.3	4.4	0.1	0.3	0.1	0.1	5.7	0.1
Ferrosilite.....	2.1	2.1	1.2	3.2	0.5	3.2	3.7	1.8	2.9	2.5	-	1.7	3.0	2.6	2.2	2.9	2.9
Enstatite.....	-	-	1.4	0.4	0.9	0.5	0.3	0.6	0.6	0.3	0.3	0.3	0.3	-	0.1	-	-
Ferrosilite.....	-	-	1.6	1.8	0.8	5.1	3.4	3.6	5.3	2.1	0.3	4.9	4.4	2.4	1.5	3.4	3.7
Magnetite.....	4.6	4.2	8.6	3.7	6.0	1.9	2.6	2.6	0.5	3.5	3.8	2.6	2.1	5.6	5.8	1.2	3.7
Haematite.....	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ilmenite.....	4.7	3.6	3.2	1.5	2.1	2.0	1.8	1.8	2.7	1.2	1.8	1.2	1.7	1.5	1.2	1.4	1.2
Apatite.....	3.0	1.7	1.7	0.3	0.7	0.3	0.3	0.7	0.3	0.3	0.7	-	0.3	0.3	0.3	-	-
CaF <sub>2</sub> .....	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.2	0.5	0.3	-	0.4	0.1	0.5	0.5	-	0.4
Varia.....	1.2	1.7	1.5	0.5	0.9	0.5	0.5	0.6	0.5	0.3	0.8	0.5	0.4	0.5	0.3	0.6	0.4

Addenda: 40471 Nepheline = 3.3, forsterite = 3.5, fayalite = 6.1;  
 50093 Nepheline = 2.3, forsterite = 3.1, fayalite = 5.7;  
 30662 Wollastonite = 3.8.

Table 5 (contd.)

	Riebeckite microgranites										Aegirine microgranites				
	30685	30758	40427	40449	40493	40495	40575	50163	50181	50187	50237	30691	40600(a)	40554	50197
Quartz.....	25.7	32.8	32.8	34.7	36.2	33.3	37.4	31.3	34.7	35.5	33.3	34.4	27.1	32.0	35.2
Orthoclase....	17.2	24.5	20.6	26.1	24.5	23.9	26.7	22.8	25.6	16.2	21.7	30.0	30.6	23.9	26.7
Albite.....	43.0	24.6	32.0	27.2	24.1	25.7	28.8	25.2	27.8	39.1	36.2	21.5	27.2	27.2	18.3
Anorthite.....	-	-	-	2.2	-	-	-	-	-	-	-	-	-	-	-
Na <sub>2</sub> SiO <sub>3</sub> .....	-	0.5	0.5	-	0.2	1.0	-	-	-	-	-	0.5	0.2	0.6	0.4
Acmite.....	6.9	12.0	7.4	-	8.8	13.9	1.8	14.3	6.5	3.2	1.4	12.9	12.5	13.4	17.1
Wollastonite	-	-	-	0.7	-	-	0.1	-	0.5	-	0.1	-	-	-	0.1
Enstatite....	-	-	-	0.6	-	-	-	-	0.2	1.3	-	-	-	-	0.1
Ferrosilite..	-	-	-	-	-	-	0.1	-	0.3	-	0.1	-	-	-	-
Enstatite....	0.2	0.1	-	0.7	-	0.1	-	0.1	0.1	2.5	0.2	-	0.1	-	0.3
Ferrosilite..	2.8	3.7	4.8	-	4.2	0.7	0.4	3.7	2.8	-	2.9	-	1.7	0.7	-
Magnetite....	1.4	-	-	5.1	-	-	4.2	-	0.2	1.6	3.0	-	-	-	-
Haematite....	-	-	-	0.3	-	-	-	-	-	-	-	-	-	-	-
Ilmenite.....	0.7	0.8	0.3	1.2	0.8	0.3	0.8	0.6	0.8	0.6	0.9	0.8	0.8	0.6	0.5
Apatite.....	-	0.3	-	0.3	-	-	-	-	-	-	-	-	-	-	-
CaF <sub>2</sub> .....	0.5	-	0.2	0.9	0.2	0.1	0.2	0.5	0.4	-	0.5	0.3	0.2	0.4	0.2
Varia.....	0.5	0.3	0.4	0.8	0.3	0.2	0.2	0.5	0.2	0.3	0.1	0.2	0.5	0.1	0.1



Table 6. Analyses of feldspar phenocrysts from Tugtutôq dykes

	Na <sub>2</sub> O	K <sub>2</sub> O	CaO	Fe <sub>2</sub> O <sub>3</sub>	Or	Ab	An
40570.....	5.82	7.84	0.72	—	46.6	49.8	3.6
50169.....	5.83	7.48	0.81	0.46	45.2	50.7	4.1
50167.....	3.92	9.95	0.53	0.45	62.4	35.0	2.6
50050.....	5.75	5.79	—	—	40.0	57.0	3.0
50187.....	7.34	5.62	0.10	—	34.9	64.5	0.6
40495.....	4.37	9.25	0.09	—	59.2	40.3	0.4

40570, 50169, hastingsite microsyenites  
 50050, 50167, riebeckite microsyenites  
 50187, 40495, riebeckite microgranites  
 50187, 40495, separated feldspar contained <20% quartz impurity  
 Or, Ab, An — as weight percent.

Table 7. Analyses of a microgranite dyke and a rhyolite sill from the Tugtutôq-Narssaq area

40435 — oxidised facies of acid member of composite dyke, central Tugtutôq (Upton, 1964a, p. 16); analyst R. Macdonald.  
 61848 — quartz porphyry sill, Narssaq (from Watt, 1966, analysis 10).

	40435	61848		40435	61848	Mode 40435
SiO <sub>2</sub> ....	76.2	73.98				
TiO <sub>2</sub> ....	0.35	0.37	q	41.6	41.0	Phenocrysts:
Al <sub>2</sub> O <sub>3</sub> ...	10.50	11.39	or	26.7	21.5	Feldspar — 2.0
Fe <sub>2</sub> O <sub>3</sub> ...	5.05	4.72	ab	24.6	25.4	Quartz — 1.6
FeO....	0.09	1.15	an	—	3.6	
MnO...	0.05	0.15	c	0.8	1.2	Groundmass:
MgO....	0.04	0.06	hy	0.1	0.2	Feldspar — 56.3
CaO....	0.30	0.72	mt	—	3.1	Quartz — 29.4
Na <sub>2</sub> O...	2.90	3.00	il	0.3	0.7	Haematite — 9.1
K <sub>2</sub> O....	4.49	3.63	hm	5.1	2.6	Zircon — 1.3
P <sub>2</sub> O <sub>5</sub> ....	<0.05	0.03	CaF <sub>2</sub>	0.2	—	Fluorite — 0.2
H <sub>2</sub> O <sup>+</sup> ...	0.94	0.83	tn	0.6	—	
F.....	0.18	—				
	101.09	100.03	<u>CIPW NORMS</u>			
O ≡ F..	0.08	—				
Total...	101.01	100.03				

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